# Structural Health Monitoring of Composite Bridges by Integrating Model-based and Data-driven Methods

**by Faraz Sadeghi**

Thesis submitted in fulfilment of the requirements for the degree of

**Doctor of Philosophy**

under the supervision of Professor Jianchun Li

University of Technology Sydney
Faculty of Engineering and Information Technology

January 2021

# Certificate of Original Authorship

I, Faraz Sadeghi declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

Signature

Production Note:
Signature removed prior to publication.

Date

January 18, 2021

*To My Beloved Parents*

# Acknowledgment

First and foremost, I would like to express a hearty sense of gratitude to my beloved mother and father, to whom I owe my life for their endless love, encouragement, support, and blessings. I am deeply grateful to you for being by my side whenever needed.

This thesis would not have been possible without the support and advice from my supervisory panel. I would like to express my sincere appreciation to my supervisor, Professor Jianchun Li, whose encouragement, guidance, and continuous support enabled me to pursue my PhD successfully. I am thankful for all the fantastic and incredible discussions we had for developing a deep understanding of the project.

I would like to express my great appreciation to my co-supervisor, Associate Professor Xinqun Zhu, who had always been generous with his contributions and ideas, and helped me conduct my project innovative and be productive. Thank you for your encouragement, mentorship, and patience.

My sincere thanks also go to the University of Technology Sydney for providing excellent research and social environment, scholarships, financial supports, facilities, and funding resources that made this thesis possible. I thank the supportive administration and technical staff at the Faculty of Engineering and Information Technology, School of Civil and Environmental Engineering, and UTS TechLab.

Finally, I would like to thank my beloved brother, who has always supported me, and his encouragement and belief in me were worth more than words.

# Publications

- Sadeghi F, Li J, Zhu X. A steel-concrete composite beam element for structural damage identification. International Journal of Structural Stability and Dynamics. 2020;20:2042015.

- Sadeghi F, Zhu X, Li J. Damage analysis of steel-concrete composite beams under static loads. Proceedings of the International Conference on Structural Dynamic, EURODYN2020. p. 1053-62.

- Sadeghi F, Yu Y, Li J, Zhu X. Damage identification of composite structures based on modal strain energy changes through general regression neural network. Journal of Engineering Structures (2021) - Under review

- Sadeghi F, Li J, Zhu X, Rashidi M. A novel slip sensory system for interfacial condition monitoring of steel-concrete composite bridges. Journal of Remote Sensing (2021) - Under review

# Table of Contents

# List of Figures

# List of Tables

# Abstract

Structural Health Monitoring (SHM) has emerged to offer a reliable and cost-effective solution for assessing and maintaining bridge structures within their long-term service life. Bridges are subjected to various undesirable operational and environmental loads that are prone to accelerate structural damage. For this reason, it is essential to timely assess the structural conditions to ensure safety. To this end, visual inspection and Non-destructive testing have been implemented in current practices to monitor the utmost damages. However, the disadvantages of these techniques, such as the need for prior knowledge about the damage location and being costly, time-consuming, and subjective even for skilled inspectors, emphasise the necessity of SHM techniques. This is because they can continually measure and use data obtained from structures. The practical applications of current SHM techniques in large-scale structures such as bridges, also have to deal with issues due to the inherent uncertainties of the FE modeling and damage detection processes. These include, for example modeling errors, measurement noises, uncertain operational environmental effects, and limited measurements. SHM of composite bridges is more challenging due to the complex behaviour of their steel-concrete composite (SCC) beam members. Monitoring the interfacial integrity of the SCC beams is crucial due to the shear connections governing the composite action that affects the overall response of the composite bridges. Consequently, developing innovative SHM techniques is essential to assess structural conditions and detect damage using data obtained from limited measurement points along the entire composite bridges.

In this thesis, the shortcomings mentioned above have been considered to develop novel methods for SHM applicable in composite bridges. To discover the gaps in our knowledge, the current model-based and data-driven methods used in SHM of composite bridges are reviewed, and their advantages and drawbacks are discussed. An innovative approach is developed for SHM of composite bridges with a limited number of static measurements. The method is based on an SCC beam element model, which can simulate

damage in the composite layers. The optimisation analysis is used to detect stiffness changes in the composite layers caused by damage, focusing on the composite interface.

Furthermore, a novel method for SHM of composite bridges is developed using dynamic measurements. A sensitivity-based damage detection approach is adopted with sensitive modal features from a few vibration modes. Principle component analysis is employed to reduce the input datasets and obtain an optimal model performance. Based on these features, an efficient machine learning model is developed using general regression neural networks to automate the dynamic-based damage identification of the SCC beams. The results show that the developed method can identify damage in composite structures, particularly in the interface.

In addition, a novel interlayer slip monitoring system has been developed for interfacial condition assessment of the SCC beams. The monitoring system is based on Ultra-flat Industrial Potentiometer Membrane. An experimental study has been carried out in the laboratory on a composite bridge model consisting of SCC beams. Then, the damages done to shear connectors are detected using the data obtained from the slip sensors. Results show that the possible damage locations in the composite bridges could be identified by analysing the interlayer slip in their SCC beam members. In summary, an integrated model-based and data-driven approach has been developed for composite structures using limited static and dynamic measurements in the thesis, and the results show the feasibility of the approach for condition assessment of composite bridges in practice.